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Pulsed Discharge Over a Surface of a Liquid

Andrey F. Aleksandrov*, Vladimir L. Bychkov†, Vladimir A. Chernikov‡, Aleksei P. Ershov§, Sergei A. Kamenshikov** Dmitry N. Vaulin♠

Faculty of Physics, M.V .Lomonosov Moscow State University, Leninskie Gory , Moscow, 119991, *Russia, bychvl@orc.ru*

Results of experimental works with the electrode discharge are represented, namely: electrode pulsed discharge experiments realization over a fluid (tap water, distilled water and alcohol - water mixture) in the form of a surface ionization wave; experiments with two forms, complete and incomplete discharges, and three stages of the discharge development. Theoretical model of discharge electrical circuit is presented.

1.Introduction

In the present work we represent results of research continuation on electric gas discharges over liquids. We consider here pulsed discharges which our first investigations were described earlier in [1] **.** Here we describe results of experiments with different liquids such as tap and distilled water, and alcohol-water a mixtures which we used in order to clarify a nature of observed discharge phenomena over a surface of a liquid. Here we present a theoretical model of discharge electrical circuit.

2.Experiment

We represent results of undertaken experimental investigations of physical processes occurring at creation of a pulsed discharge over a surface of a liquid, for which we used usual tap water, distilled water, diluted alcohol, kerosene, and machine oil. Experiments were carried out with a help of two installations. A scheme of the first is represented in the Report for the 4-th stage of the present Project and a scheme of the second one is represented in Fig.1.

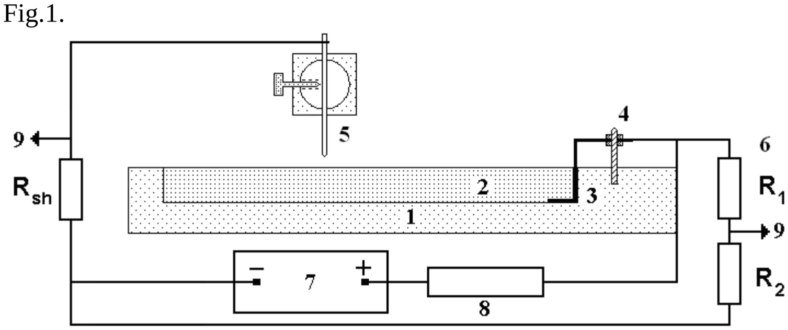

Figure 1. A scheme of the installation.

An investigating liquid was poured into a cavity (2), cut in unbroken piece of organic glass (1). The cavity sizes were 30×12 cm. A positive electrode- anode (5) was located directly over a liquid, it was made in a form of a sharpened steel rod 4 mm in a diameter. It was possible to vary a distance between it and a liquid in a range (1-20) mm. A flat negative electrode- cathode (3) was located straightly in the liquid. It was connected with a power source through an additional bar (4) . Water was a second electrode at initial linear breakdown.

A pulsed modulator (7) was applied as a feeding source of an electric scheme. It allowed to obtain pulsed with the duration from 10 μs to 1 ms. A power source's outlet voltage in a pulse was varied from 7 to 25 kV with a step

*Head of Chair
† Leading researcher
‡ Associated Professor
§ Associated Professor
**,♠ Post graduate students

250 V. A ballast resistance (8) was applied for limitation of a discharge current; its value was varied from in a range (1-10) kOhm. The voltage drop on a discharge was determined with a help of a ohmic voltage divider R_1, R_2 (6) with a coefficient of a division equal to 1000. The discharge current was measured with a help of a shunt (R_{sh} = 0,5 Oм), which was in series included in the discharge circuit. Pulsed signals from the voltage divider and the shunt were delivered to a two-beam digital oscilloscope (9). A discharge filming was undertaken with a help of digital camera.

Most of experiments were carried out in the mode when a liquid and dipped electrode had a role of the anode, and the upper electrode had a role of the cathode. Initial conditions of discharge creation were changed during undertaking of experiments, namely: a distance between electrodes was varied over a horizontal line (L), a height (H) of the cathode position over a liquid, we changed initial voltage of the source (U_0) and a duration (τ)of a discharge pulse. In addition we changed a value of the ballast resistance.

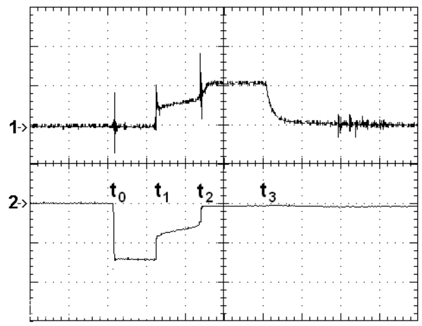

Fig. 2. Waveforms of a current (1) and a voltage drop (2) on a discharge. L = 34 mm, H = 7,1 mm, U_0 = 13,3 kV, scan 25 µs/cm, sensitivity over a current is 5 V/div, sensitivity over a voltage is 10 V/div. Discharge pulse duration is 100 µs.

3. Experiments with a discharge over water

We have undertaken main part of experiments with a help of usual water. As we noted in previous report, the very first experimental series showed that the pulsed discharge over water surface has a complex temporary evolution, which consists of a number of different stages. Let us consider once more a discharge transition process from one stage to another with a help of typical waveforms of a current and a voltage represented in Fig.2.

From the represented waveforms one can see that there is no a discharge starting from the moment of a voltage giving to electrodes (t_0) and a time t_1. This time interval corresponds to static discharge gap breakdown delay with respect to a beginning of the voltage pulse giving. Then a breakdown takes place in the time moment t_1, and a linear spark plasma channel appears. It develops along a liquid surface practically perpendicular to the opposite side of the cavity. A process of the spark discharge origination is accompanied by the voltage drop between the electrodes and appearance of the discharge current.

One can see in Fig.2 that the voltage on the discharge dose not stay constant after the moment t_1, but slowly decreases, but the discharge current raises at the same time. Such changes of the current and the voltage continue until the moment t_2, then again a sharp drop of the voltage on the discharge takes place and a corresponding rise of the discharge current takes place. After that the voltage on the discharge and the current stay constant until the end of the pulse (t_3).

Revealed temporary behavior of the discharge current and the discharge drop on the discharge can be explained by existence of different stages of the discharge over a surface of water. The first stage takes place after some definite lag time, it corresponds to initial spark air breakdown between the upper electrode and water, and it finishes with linear plasma channel formation. At that a total current flows over the formed spark channel and some definite water volume. Since water conductivity is relatively small then a total resistance of a circuit over which the current flows is rather high; this limits a value of the discharge current and a level of the voltage on the discharge decrease. A slow rise of the discharge current and a corresponding decrease of the voltage on the discharge is observed starting from the moment t_1 during the time interval $\Delta = t_2 - t_1$; i.e. the second stage is realized, a discharge transformation from one to another form takes place during it. During this time interval a wave of a surface ionization propagates from the cathode to the anode with some definite velocity, which forms a plasma channel over a water level. At that the summed resistance of the plasma channel and of a part of water in which the discharge current is flowing drops down. The discharge current rises simultaneously with drop of total resistance; and the voltage drop on the discharge decreases, respectively.

The surface ionization wave reaches the anode in the time moment t_2, and a space between the cathode and the anode is closed by the formed plasma channel. The summed resistance of the discharge channel drops sharply, this leads to increase of the current and decrease of the voltage on the discharge. The second stage of discharge development over a surface of water finishes in this moment. After that values of the discharge current and the voltage on the discharge stay practically constant until an end of the voltage pulse independently of its duration ($\tau = t_3 - t_0$), the third stage of the discharge takes place.

Note that the discharge over a surface of water can be complete or incomplete with respect to initial conditions (amplitude and duration of a pulse, a distance between electrodes). In Fig.3 one can see photos of such two discharge forms. A determining factor at that is a rather simple relation between three parameters of the discharge: a duration of a voltage pulse (t_i), a distance between the electrodes (L), and a velocity (V) of the discharge propagation over a surface of water in the second stage. These three parameters are naturally connected by a following formula:

$$L = V \times t_i \,. \qquad (1)$$

So the discharge has an incomplete character if discharge propagation velocity value is such (relatively small) that the ionization wave running from the anode to the cathode does not have time to reach the anode during the time of the pulse duration (see Fig.3a). If the ionization wave velocity is relatively high then the discharge has a time to reach the anode during the voltage pulse duration (or shorter time), and the complete discharge form is realized.

We have to emphasize that a velocity of discharge propagation is evidently determined by a value of electric field strength in the discharge gap, which depends on the voltage drop on a discharge or on its part. But the voltage drop on the discharge is determined by the voltage pulse initial voltage and a relation between the ballast resistance and a resistance of the discharge or its part.

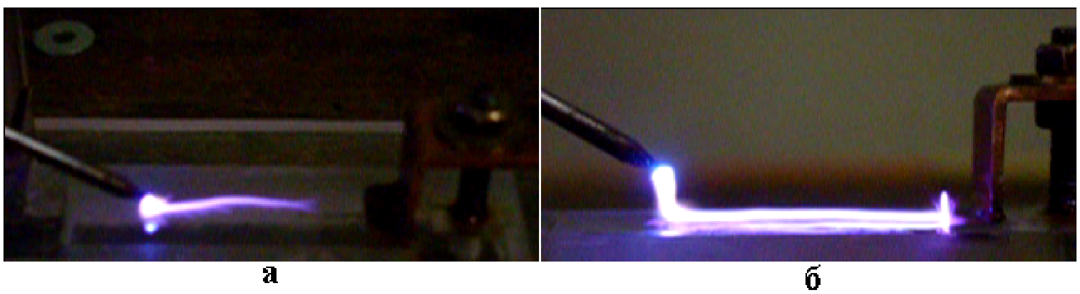

Figure 3. Discharge photos. R_b = 3 kOhm, L = 50 mm, τ =100 μs. a) an incomplete discharge H = 4,0 mm, U_0 = 10 kV, b) a complete discharge, H = 8,0 mm, U_0 = 21 kV.

Thus the experimental result determining a type of the discharge development over a surface of water (or any other liquid) is the time of the second stage or the time of ionization wave propagation from the cathode to the anode. So at undertaking of experiments we first of all have determined the time of, namely, the second stage and its dependence on different initial parameters. For example in Fig. 4-a one can see a dependence of the discharge development second stage time on initial pulse voltage at two values of the ballast resistance value. It can be seen that the time of the second stage sharply drops with rise of the pulsed voltage; it comes to some definite value determined by an experimental measuring value. It also decreases at transition to a smaller value of the ballast resistance.

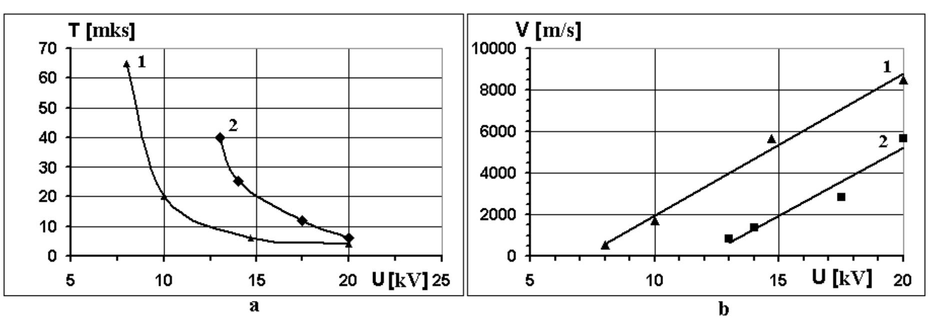

Figure 4. a) a transition stage time with respect to U_0; b) a velocity of a discharge propagation with respect to U_0. L = 50 mm, H = 5,0 mm, τ =500 μs, 1 – R_b = 1 kOhm, 2 – R_b = 3 kOhm.

In Fig. 4-b one can see a dependence of average ionization wave velocity on initial voltage in a pulse value also for two values of a ballast resistance. The average ionization wave velocity is determined with a help of the formulae (1) at known value of L and measured values of t_i. It can be seen that the velocity rises with rise of the initial voltage and at decrease of the ballast resistance.

For better understanding of physical processes occurring at the discharge propagation over a surface of a liquid let us consider approximate equivalent discharge electric circuit scheme main elements of which are represented in Fig.5.

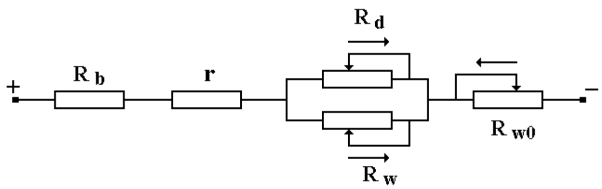

Fig. 5. Approximate equivalent discharge electric circuit scheme.

In this scheme R_b is a ballast resistance, r is a resistance of a linear discharge part that is perpendicular to a surface of a liquid, R_d is a resistance of a discharge propagating over a surface of a liquid, R_w is a resistance of a part of a liquid switched parallel to the discharge, and R_{w0} is a resistance of remained part of a liquid. Let us designate by R_Σ a summed resistance of a discharge and of a part of a liquid switched parallel to it; then:

$$R_\Sigma = \frac{R_d \times R_w}{R_d + R_w} \quad . \tag{2}$$

One can see that $R_\Sigma = R_d$ at $R_w » R_d$, i.e it equals to the discharge resistance.
In the represented formula we use

$$R_d = \frac{\rho_d \times L_d}{S_d}, \qquad R_w = \frac{\rho_w \times L_d}{S_w}, \qquad R_{w0} = \frac{\rho_{w0} \times (L_0 - L_d)}{S_{w0}}, \tag{3}$$

here ρ_d , ρ_w , ρ_{w0} are the specific resistance of the discharge and separate parts of the liquid , respectively, S_d , S_w , S_{w0} corresponding cross sections in the discharge and in the liquid where the discharge current flows. L_d и L_0 are the discharge length and the distance between the cathode and the anode, respectively. Evidently that one can suppose in the limit of measuring error that $\rho_w = \rho_{w0}$ и $S_w = S_{w0}$.

It is easy to show that a value of the discharge current in the circuit (I_d) is determined by an equation:

$$I_d = \frac{U_0}{R_b + r + R_\Sigma + R_{w0}} \quad . \tag{4}$$

Also in limits of the experimental error one can suppose that $R_b » r$, and

$$I_d = \frac{U_0}{R_b + R_\Sigma + R_{w0}}. \tag{5}$$

A potential difference between a head part of the propagating discharge and the cathode is determined by a voltage drop on a remained part of the liquid (U_w), i.e.:

$$U_w = \frac{U_0 \times R_{w0}}{R_b + R_\Sigma + R_{w0}}. \tag{6}$$

Using equations (2) one can easily get a following expression for a full resistance of the circuit R_c:

$$R_c = R_b + \frac{\rho_w \times L_d}{S_w} \times \left(\frac{L_0}{L_d} - \frac{1}{1+\Delta} \right) = R_b + \frac{\rho_w \times L_0}{S_w} - \frac{\rho_w \times L_d}{S_w} \times \frac{1}{1+\Delta} \quad . \tag{7}$$

here:

$$\Delta = \frac{\rho_d \times S_w}{\rho_w \times S_d}$$

Then one obtains a following expression for U_w:

$$U_w = \frac{U_0 \times \frac{\rho_w}{S_w}(L_0 - L_d)}{R_b + \frac{\rho_w \times L_d}{S_w} \times \left(\frac{L_0}{L_d} - \frac{1}{1+\Delta}\right)}. \tag{8}$$

If one knows a potential difference between the head part of the propagating discharge and the cathode then he can determine an average value of the electric field strength in the area between the head part of the discharge and the cathode:

$$E_m = \frac{U_w}{(L_0 - L_d)} = \frac{U_0 \times \frac{\rho_w}{S_w}}{R_b + \frac{\rho_w \times L_d}{S_w} \times \left(\frac{L_0}{L_d} - \frac{1}{1+\Delta}\right)}, \tag{9}$$

or:

$$E_m = \frac{U_0 \times \frac{\rho_w}{S_w}}{R_b + \left(\frac{\rho_w \times L_0}{S_w} - \frac{\rho_w \times L_d}{S_w} \times \frac{1}{1+\Delta}\right)}. \tag{10}$$

It follows from the last expression that the electric field strength at $L_d = 0$ is equal to

$$E_{mi} = \frac{U_0 \times \frac{\rho_w}{S_w}}{R_b + \frac{\rho_w \times L_0}{S_w}}, \tag{11}$$

i.e. it is defined only by resistance of the ballast and water which depends on a distance between the cathode and the anode. One has at $L_d = L_0$:

$$E_{mf} = \frac{U_0 \times \frac{\rho_w}{S_w}}{R_b + \frac{\rho_d \times L_0}{S_d} \times \frac{1}{1+\Delta}}. \tag{12}$$

Thus the electric field strength in the area of the head part of the discharge weakly rises at the discharge propagation from the anode to the cathode along the surface of a liquid and the field value stays constant at the discharge motion only at R_b » ($R_\Sigma + R_{w0}$).

At the discharge reaching of the cathode the current channel is formed, which resistance drops down sharply, this leads to an increase of the discharge current and correspondingly to the voltage drop on the discharge, that was experimentally detected in the waveforms.

Thus supposing that a velocity of the ionization wave propagation (i.e. a velocity of the discharge motion) depends mainly on a value of the electric field strength in the discharge gap one can easily get from the formula (10) that the electric field and consequently the velocity will rise with rise of the initial voltage in the pulse. The electric field strength and the discharge velocity of motion will also rise with decrease of the ballast resistance in accordance with (10), this is in full agreement with the experimental data represented in Fig.ч.4-б.

For a clarification of an impact of relation between the ballast resistance value and of the discharge itself on the discharge development second stage time we have undertaken experiments in which the summed discharge resistance was varied in a result of a liquid conductivity variation, in water in particular. For this purpose we either heated water or changed it for a diluted alcohol with different concentration of alcohol. In Fig.6-a one can see the discharge development second stage time dependence on heated water temperature for two values of the ballast resistance. One can see that the discharge development second stage time also rises with increase of water temperature. In addition this time increases with rise of the ballast resistance as in previous experiments.

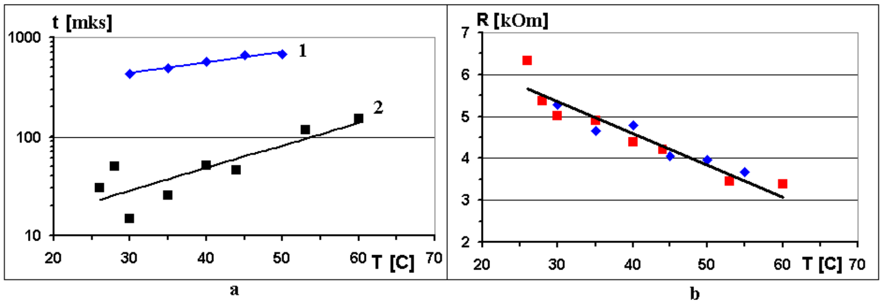

Figure 6.a) A time of a transition stage with respect to a temperature; б) initial air resistance with respect to a temperature. L = 50 mm, τ =700 μs, H = 5 mm, ♦ - R_b = 8 kOhm, ■ - R_b = 4 kOhm .

Obtained second stage time dependence on water temperature can be easily explained with a help of the formula (10). It is well known that water conductivity rises with increase of its temperature, so a specific resistance of water ρ_w drops down, and the electric field strength and the ionization wave decrease respectively. The discharge propagation velocity decrease leads to rise of the second stage time; this is observed in the experiments. On a basis of obtained discharge current and voltage waveforms one can calculate initial water resistance corresponding to finishing of the discharge gap linear breakdown between the cathode and water and beginning of the discharge second stage.

A dependence of water initial resistance on temperature obtained by this way is represented in Fig.6b. One can see that water initial resistance drops down with rise of temperature. We have to mark that calculated water resistances practically do not depend on values of the ballast resistance at any temperature as it was expected.

We added some definite amount of alcohol to water in order to decrease water conductivity and hence for increase of its specific resistance; this allowed to obtain a mixture with a given concentration of alcohol.

In Fig.7-a one can see the discharge second stage time dependence on alcohol concentration in water .

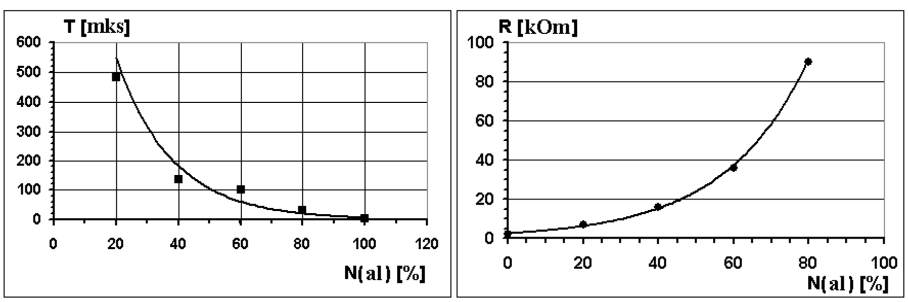

Figure 7. a) a transition stage time with respect to alcohol concentration; b) an initial resistance with respect to alcohol concentration. R_b = 8 kOhm, L = 50 mm, τ =700 μs, H = 5 mm.

It follows from the represented figure that a specific resistance rises with increase of alcohol concentration in water, and the electric field strength and the discharge velocity rise according with the formula (10) , this leads to the second stage time decrease, which was observed experimentally. In Fig. 7-b one can see a dependence of initial mixture's dependence on an alcohol concentration. One can see that the initial resistance also increases with rise of the alcohol concentration in the mixture, this testifies to rise of the mixture's specific resistance.

One has to mark one typical fact: the electric field strength and the discharge propagation velocity rise at increase of a specific resistance of a liquid in accordance with (10), hence the second stage time decreases.

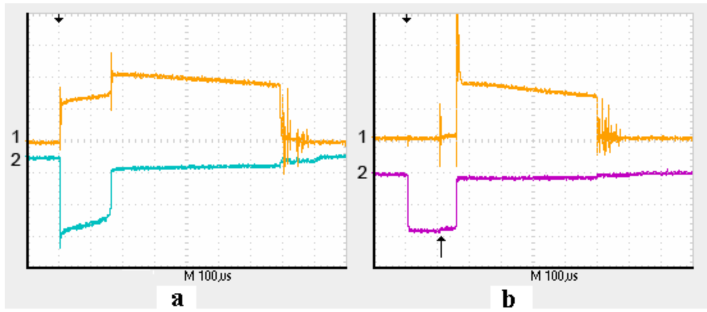

Figure 8. Waveforms: 1- a discharge current 2- a voltage on the discharge. a) usual water, H=5 mm, L=70 mm, U_0 = 20,1 kV, R_b = 2 kOhm. b) distilled water, H=8 mm, L=70 mm, U_0 = 23,8 kV, R_b = 2 kOhm.

However, a total resistance of the discharge circuit increases at that, and variations of the current value and of the voltage drop become insignificant. As a typical example in Fig.8 one can see waveforms of a current and a voltage for a case of usual (Fig. 8a) and distilled water (Fig. 8b).

Black arrows above in these waveforms indicate a moment of a voltage pulse delivery to the electrodes. It follows from Fig.8a that the linear breakdown of the discharge gap between the cathode and water surface takes place practically immediately at giving of the voltage to the electrodes, and the second stage of discharge development starts. One can see a substantial voltage drop on the discharge and a corresponding rise of a current. In waveforms in Fig.8b by an arrow from below we indicate a start of a linear breakdown in case of the distilled water with much higher resistance. Thus in this case one observes some definite time of a breakdown lag about which we marked earlier. The second stage of the discharge development starts after the breakdown. Let us firstly mark that it is much shorter, this corresponds to the proposed model of the discharge development. The rise of the specific resistance leads to increase of the electric field and ionization wave velocity, and hence to the decrease of the second stage. Secondly, variations of the discharge current and voltage during this stage are practically unnoticeable.

A similar picture is observed also in the case of the discharge propagation over a surface of water-alcohol mixture at high concentrations of the last one. In Fig.9 one can see waveforms of the current and voltage in this case.

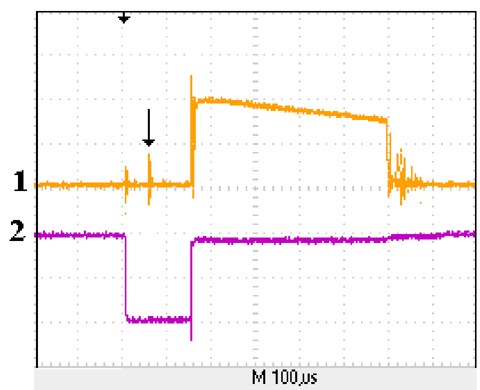

Figure 9. Waveforms: 1- of the discharge current, 2- of the voltage on the discharge.
80% of alcohol in water-alcohol mixture. H=5 mm, L=70 mm, U_0 = 22 kV, R_b = 2 kOhm.

A small arrow in these waveforms mean a moment of the voltage giving to the electrodes a the large one- the moment of the linear breakdown and a beginning of the second stage. It can be seen from Fig.9 that in this case also are practically unnoticeable variations of the electric current and voltage values during the second stage at the given sensitivity of the oscilloscope channels. One can determine temporary variations of summed discharge resistance and those of a part of the liquid with a help of oscilloscope measuring data during the second stage of the discharge development. Results of such calculations for the waveforms represented in Fig.8 are represented in Fig.10.

It follows from the represented dependences that the summed resistance of discharge circuit practically linearly drops from a value corresponding to initial water resistance to some value which is defined by a resistance of the

discharge channel itself. A plasma channel is formed at discharge head part reaching the anode; it causes a sharp rise of the discharge current value that leads to the same sharp drop of the resistance of the discharge itself and decrease of the voltage drop on it.

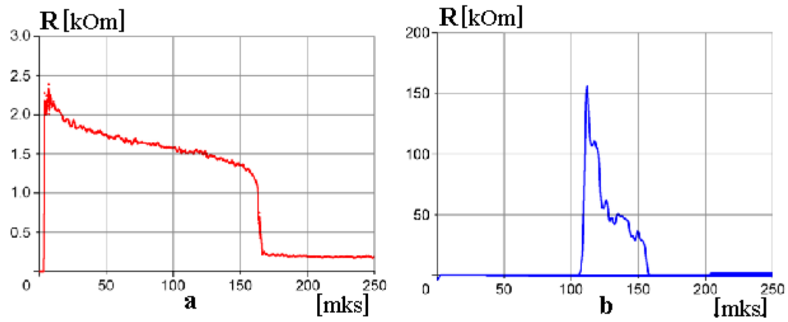

Figure 10. Summed discharge resistance dependence on a time of the second stage. a) usual water, H=5 mm, L=70 mm, U_0 = 20,1 kVB, R_b = 2 kOhm. b) distilled water, H=8 mm, L=70 mm, U_0 = 23,8 kV, R_b = 2 kOhm.

We have to mark that the initial resistance of the distilled water is practically by two orders of a magnitude is greater than those of usual (tap water) as it follows from represented graphs, but in two cases at closing of the discharge channel with the anode the final summed resistance is defined only by a resistance of formed current channel and is of about of several hundreds Ohm.

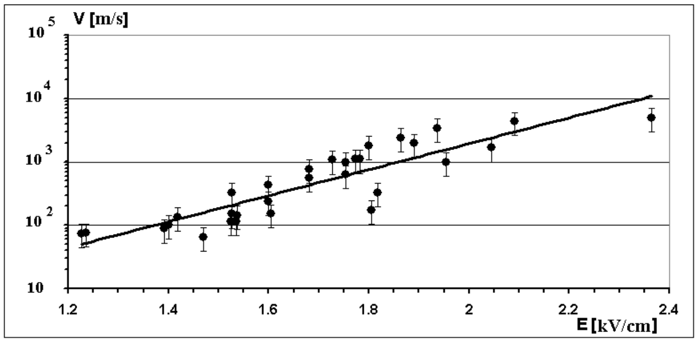

Figure 11. Discharge propagation average velocity dependence on average electric field strength obtained at different initial conditions.

Obtained experimental results allow to determine a discharge propagation average velocity over a surface of a liquid as a ratio of known distance between the electrodes and experimentally measured time of the discharge development second stage. In addition one can find an average value of the electric field strength as a ratio of measured value of a voltage drop on the discharge and known distance between the electrodes. Obtained results allow to determine discharge propagation average velocity dependence on an value of average electric field strength. An example of such a dependence is represented in Fig.11. Separate points in this graph were obtained at different initial conditions: initial voltages and feeding pulse durations, different distances between electrodes, different resistances of a ballast and a liquid, different heights of the cathode over a surface of a liquid. But in all these cases we measured discharge propagation velocity values and those of electric field strength with a help of described method.

One can see in the represented dependence that practically all the points obtained at different initial conditions lie on a curve defined by an equation: $\mathbf{V = 0{,}15 \times \exp(4{,}7 \times \mathit{E})}$,

here discharge propagation velocity V is expressed in [m/s], and electric field strength E in [kV/cm].

In addition we have undertaken a series of experiments in which we measured a duration of the voltage pulse at practically constant other initial parameters.

In Fig.12 one can see typical photos of the discharge obtained at different durations of the high voltage pulse at the following constant initial conditions: a height of the cathode position over water surface is H = 5 mm, a distance between the electrodes is L = 20 cm, an initial voltage amplitude in the pulse U_0 = 28,2 kV.

One can see in represented photos that the discharge reaches the anode only during the time about of 900 μs; at smaller times it has an incomplete character.

Let us mark a typical feature of the photos: the discharge in them is recorded in a form of two jets propagating over a surface of water. In realty these two jets represent an image of the discharge itself (the upper jet) and its reflection in water (the lower jet). In this case one can easily see a dark gap between jets which verifies that the discharge propagates namely over a surface of water without touching it; and only its head part contacts with water during the discharge propagation.

Δt = 50 mks **Δt = 250 mks**

Δt = 500 mks

Δt = 900 mks

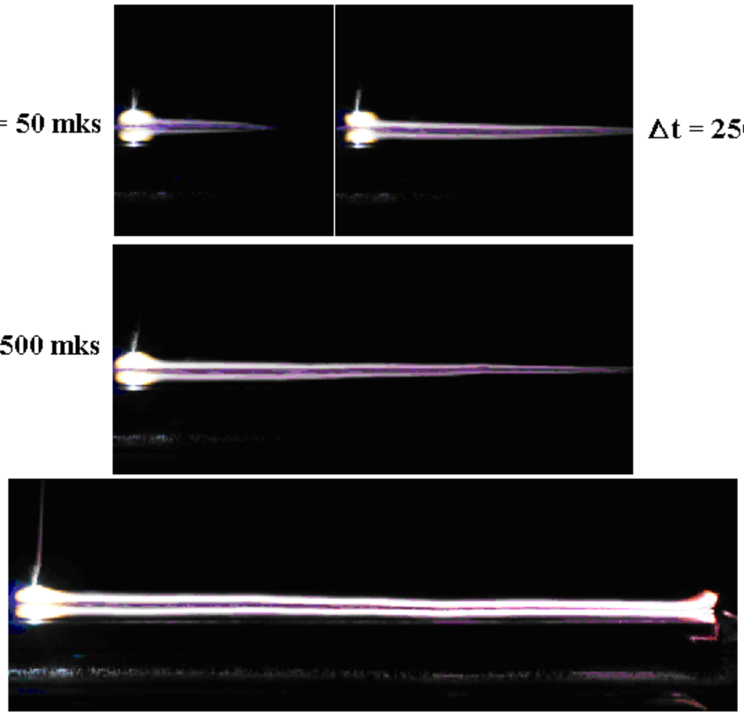

Figure 12. Discharge photos at different pulse durations.
A scale is constant for all the photos, maximal discharge length is 20 cm.

4. Streamers of electrode discharges

In order to qualitatively describe the situation we applied developed theory from [2], namely devoted to the streamer propagation of high-speed spark discharge. We did not follow recommendations from [2] to consider this wave as some temperature wave over the conducting liquid with temperature release since results obtained according to Zeldovich thermal wave [3] gave too slow velocities of the wave in comparison with our experiments. In our case we have short spark in comparison with long sparks considered in [2], and we also did not observe evaporation which could demonstrate the leader mechanism, which develops with release of high temperature channel [2].

According to [2] the electric field on a head of the streamer produces initiation electrons in front of it, creating the ionization wave with a velocity

$$v_c \approx \frac{v_{im}\, r_m}{(2k_f - 1)\ln\dfrac{n_m}{n_0}} \qquad (13)$$

Here k_f ($k_f > 1$) is connected with the ionization coefficient by the equation $\nu_i = \nu_{im}(E/E_m)^{k_f}$, r_m is the radius of the streamer head, the field changes in front a head $E = E_m(r_m/r)^2$ up to its surface $r = r_m . n_e(r_m) \equiv n_m$ -is the number density of electrons in the head of the streamer. We approximate the ionization frequency by the function $\nu_i = \nu_{im}(E/E_m)^{k_f}$, where $k_f > 1$.

$$n_m = \frac{2\varepsilon_0 \nu_{im}}{(2k_f - 1)e\mu_e \ln\frac{n_m}{n_0}}. \qquad (14)$$

The density at the front by many orders of magnitude higher than those of n_0 - the initial number of electrons in front of the streamer.

Using formulas and data of [4] we tried to get estimates and make preliminary conclusions on processes taking place in our experiments. Values of Taunsend coefficient in the range of fields *E*~80-300 kV/cm is approximated by the function (for estimates we use this range of electric fields)

$$\alpha \approx 4500 \cdot \left(\frac{E, kV/cm}{300}\right)^{3/2} cm^{-1},$$

and $\nu_i = \alpha \cdot v_e$ [3] to this region corresponds $k_f = 5/2$. By different indirect data [2] r_m~10^{-2}÷10^{-1} cm. Let us assume r_m~0.1 cm, E=30 -100 kV/cm, E/N= 10^{-15}-$3\cdot10^{-15}$V·cm^2, average electron mobility $\mu_e = v_e / E$ ≈270 cm^2/(V·s), α ≈140-870 cm^{-1}, v_e≈$8\cdot10^6$-$3\cdot10^7$ cm/s [2,4] so ν_{im} = $1.1\cdot10^9$-$2.6\cdot10^{10}$ s^{-1}. For clean air n_0= 10^6 cm^{-3} [2].

From (14) one has

$$n_m = \frac{(1{,}1 - 26)\cdot 10^{12}}{\ln(n_m / n_0)}, \text{ cm}^{-3},$$

or for this case n_m= 10^{11}-10^{12} cm^{-3}, and from (1.1.13) it follows that v_c= 2,4· 10^7÷4,7·10^7 cm/s. This value obtained in clean air is for about of an order of magnitude greater than the experimental one, but obtained in air at presence of water or alcohol vapors. The reason for this can be a decreased value of initial electrons due to absorption of UV radiation (source of initial electrons in air) by water or alcohol molecules. In this case $\ln(n_m / n_0)$ in the formula (13) has to increase significantly and the value of the plasma stream has to decrease to the observed value.

Conclusions

Undertaken experiments with electrode pulsed discharges over surfaces of liquids (tap water, distilled water, alcohol-water mixtures) have shown that there are two types of a discharge (complete and incomplete) over a surface of a liquid and several stages of the discharge are realized. Theoretical analysis of electric circuit scheme allowed to clarify a role of each of these stages and demonstrate their existence in different experimental situations.

Theoretical approach of ionization wave – the streamer motion of Yu.P. Raiser has been applied, it qualitatively explains a value of electrode spark streamer velocity. Used formula gives values about an order of magnitude greater than the observed in experiments with spark discharge over water and alcohol. This can be connected with absorption of UV radiation (source of initial electrons in air) by water or alcohol vapor molecules.

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